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Subject: Geometry Simplifications for β=0.175 Spoke Resonator

The very good RF–performance of spoke resonators so far has led to an investigation if their production cost could be reduced by simplifying costly details of the geometry. Also the use of lower RRR niobium in some of the ports has been evaluated.

Introduction

Usually in RF–structures smooth transitions between differently shaped RF–surfaces are desirable to reduce peak surface fields. These smooth transitions, like for example filleting at the spoke to outer cavity wall intersection or the filleting at the spoke beam hole intersection (see Figure 1) can significantly increase the production costs of a structure. The very good RF–performance of simplified spoke resonators tested at ANL [1] and LANL [2] indicate that filleting at these places could be omitted without a major penalty in cavity performance. This memo describes the comparison of MAFIA simulation results for a β=0.175 spoke resonator with and without filleting. Furthermore, also the option of an upright cylindrical spoke has been looked at.
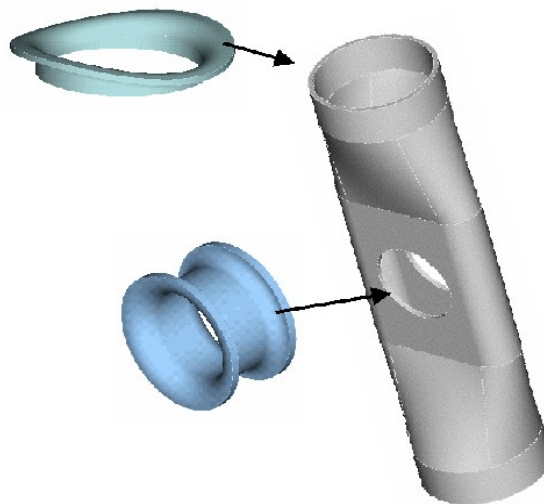

Figure 1: When filleting is used, special parts or machining steps have to be performed for the spoke to outer cavity wall and spoke to beam hole transitions. This detailed view is taken from the ADTF review presentation by AES [3].

Another cost reduction measure could be the use of reactor grade niobium in the power coupler ports. This option is evaluated at the end of this memo.

The Original Optimized Cavity with Filleting

The original design of the β=0.175 ADTF spoke resonator [4] resulted in a spoke shape with smooth transitions that was much more complex than the simple proof–of–principle cavities designed by ANL for the RIA project. This design has very low peak surface fields. As the only major restriction to complexity in this design a restriction has been imposed on the perimeter of the spoke. While the cross–section is changing along the length of the spoke, the perimeter has been kept constant. The cost study presented in the ADTF Design Review in April was based on this design. Figure 2 shows the peak surface field amplitude on the spoke surface.
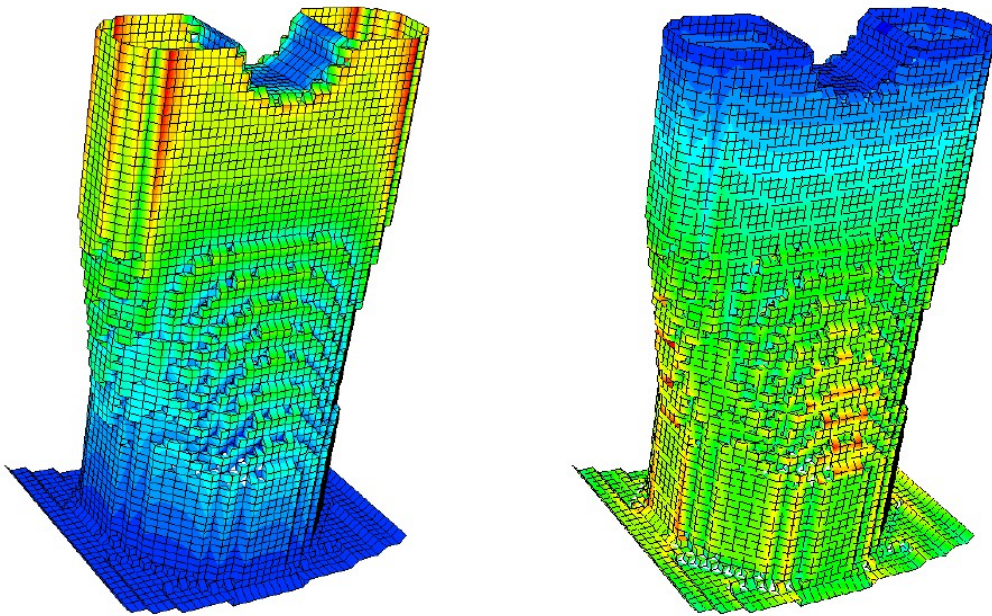

Figure 2: This plot shows the electric (left) and magnetic (right) field amplitude at the surface of the optimized spoke with filleting.

The Optimized Cavity without Filleting

In a first step we investigated a simplification of the spoke to outer cavity wall interface. Here the fillets in the spoke cavity wall transition have been omitted. The simulations with MAFIA indicate that this hardly affects the peak surface fields. This is not surprising, as the peak magnetic field amplitude predominantly is determined by the diameter of the spoke which is not reduced below the optimum value of 9 centimeters by this modification (see Figure 3, right).

In the next step also the interface between the spoke body and the beam hole at the aperture has been simplified by removing the fillets. The effect of this modification is less obvious, as it adds "sharp" corners in a high electric field region. Again, looking at the peak electric field amplitude in the aperture area (see Figure 3, left), the location of

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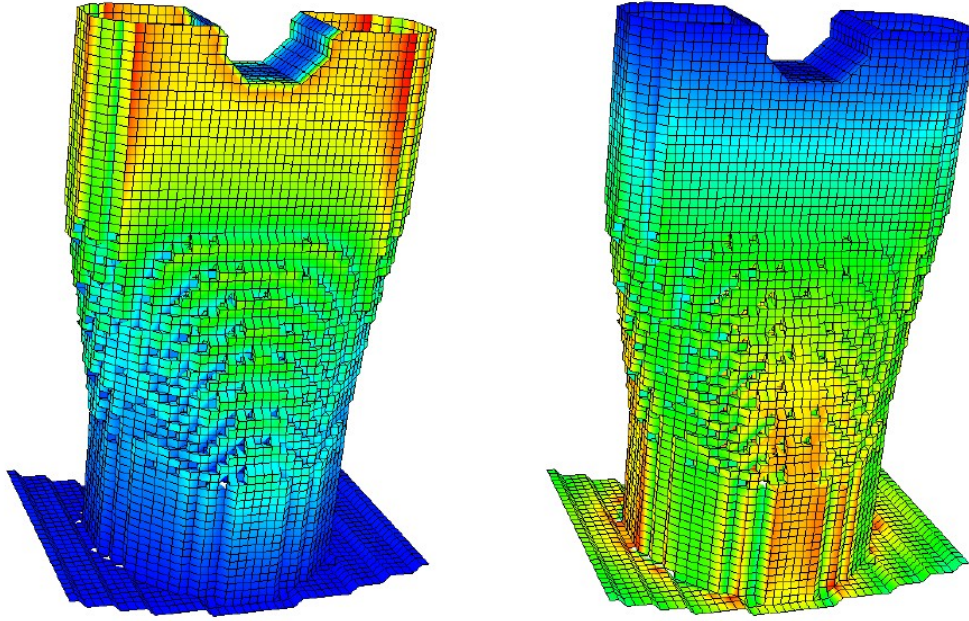the peak electric field is not changed by this change.

Figure 3: This plot shows the electric (left) and magnetic (right) field amplitude at the surface of the modified spoke without filleting at spoke base and aperture. Blue indicates the lowest and red the highest amplitude. It can be seen that the highest values are not at the "non−smooth" transitions. Thus simplification of the fabrication procedure by removing the filleting does hardly affect the performance in terms of operational peak surface fields.

An Upright Cylindrical Spoke without Filleting

To do a closer comparison with the simple ANL geometry, also a cylindrical spoke has been investigated. The diameter of this spoke has been chosen at half the total gap length of the cavity. It had been demonstrated by Ken Shepard [5] that this gives the best peak surface fields for such a structure. While the peak magnetic field did not increase prohibitively, the peak electric field at this low β is too high for a high gradient operation. The reason for this strong increase in peak electric field is in the required size of the beam aperture that moves the corners of the bore opening into the high electric field region of the fairly small spoke cylinder.
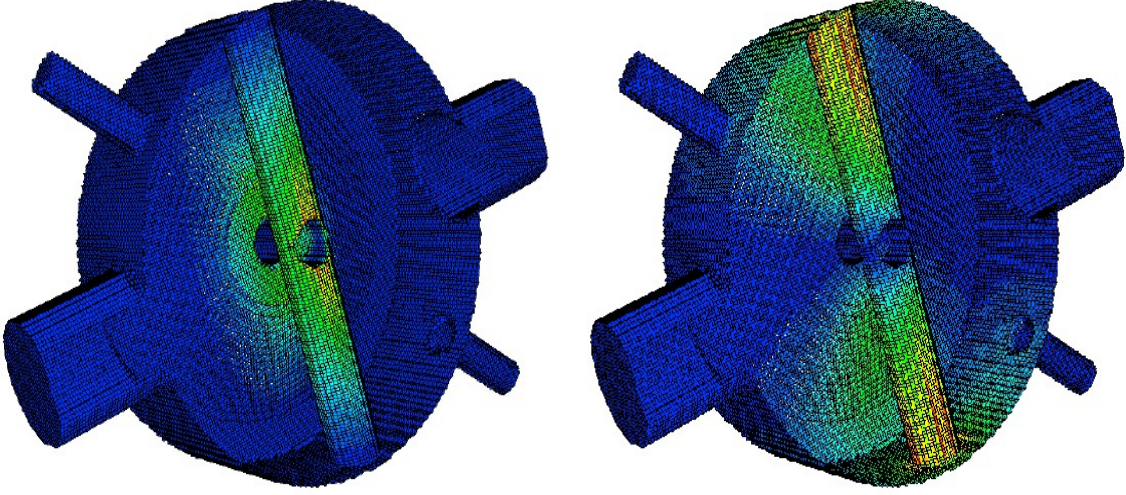
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Figure 4: For completeness, also a homogeneous, upright cylindrical spoke has been evaluated. While the peak magnetic field amplitude is reasonable, the electric peak fields increase significantly. The major disadvantage of this approach is the tight space for fitting the beam aperture into a reasonably sized spoke cylinder.

Summary and Conclusion of the Filleting Effect

Table 1 gives a comparison among the cases studied. Note that the absolute values of the optimized numbers are slightly different than previously published. The reason is a non–optimized discretization of this model. For a proper comparison all models have been discretized in a similar fashion with approximately 2.5 million cartesian elements. An optimized "smooth surface" discretization would have been an unreasonable calculation effort for the scope of this comparison.

	Original with Fillets	*No Fillets @ Base*	*No Fillets @ Base/Aperture*	*Cylindrical without Fillets*
T	0.80070	0.80230	0.80360	0.81710
Q_0 @ 70 nΩ	8.76E+08	8.61E+08	8.60E+08	9.15E+08
$ZT^{2/}Q$	135.4	135.7	137.1	215.4
E_{pk}/E_a	2.68	2.86	2.66	3.73
B_{pk}/E_a	69.14 G/MV/m	71.64 G/MV/m	70.94 G/MV/m	73.02 G/MV/m

Table 1: This table shows a comparison of some RF–properties of the cavity modifications studied. The comparison shows that the fillets in the optimized spoke design do hardly influence the peak surface fields and thus could be omitted for simplicity reasons.

The simulation show that fillets can be omitted without a penalty in operation. A cylindrical spoke without further optimization work is not suitable for this low β structure, but it might be an option for the higher β cavities.

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Simulations on the Use of Reactor Grade Niobium

Because the cost of high–RRR (RRR=250) niobium is fairly high, the production cost of the spoke resonators could be reduced (though probably not much) if the largest ports could be done in reactor grade (RRR=40) niobium instead. To study the increased RF losses in the coupler pipe at the cavity, a cavity with coaxial coupler (inner and outer conductor) has been modeled. From two runs with different boundary conditions in the coaxial coupler port the traveling wave RF–fields in the cavity–coupler transition can be constructed [6]. Table 2 gives the cavity losses and quality factors for RRR=250 niobium versus a mixed use of niobium.
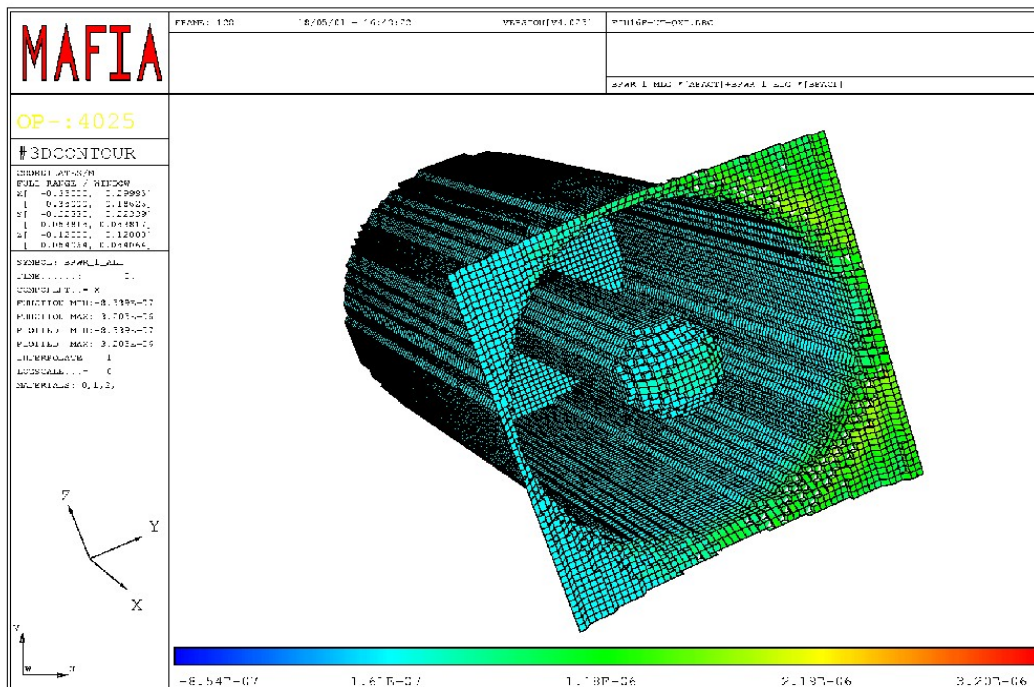

Figure 5: Here the losses in the coupler port are shown. They are non–symmetric due to the 45 degree angle towards the spoke position. The traveling wave losses in this line together with the harmonic losses in the cavity have been used to determine the influence of reactor grade niobium for the outer conductor up to the first flange on the cavity Q.

Note that the losses in the coupler port are only the ones due to the cavity field level itself. The losses due to the beam power transmitted are not considered for this excericse.

	4K, RRR material	*4K, reactor grade material*	Δ [%]
Losses in 2nd port	2.250E−05 W	1.410E−04 W	N/A
Losses in coupler port	1.740E−04 W	1.090E−03 W	N/A
Losses in cavity	0.1 W	N/A	N/A
Q_0 (for full structure)	8.760E+08	8.670E+08	1.05%

Table 2: The losses are given for a field level of 1 MV/m and a total surface resistance of 70 nΩ for the RRR grade material. The losses for the reactor grade material have been scaled with the RRR ratio. The Q−degradation is small enough to allow this simplification if desired. The decision on a cost basis still needs to be done.

Acknowledgments

I would like to acknowledge the support by Richard LaFave. He provided me with all necessary cavity models and provided useful input into the possible cavity simplifications.

References

[1] Kelly, Kedzie, Shepard, "Cold Tests of a Spoke Cavity Prototype for RIA", to be published at PAC2001, June 2001

[2] Tajima, "ANL Spoke Cavity Tests", presented at the April 2001 ADTF Review

[3] Rathke, Myers "Cost Study Results (AES)", presented at the April 2001 ADTF Review

[4] Krawczyk, "Spoke Cavity Physics Design" presented at an Internal Design Review in January 2001

[5] Ken Shepard, private communication

[6] Pascal Balleyguier, "External Q Studies for the APT Superconducting Cavity Couplers", Linac98, Chicago, August 1998

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